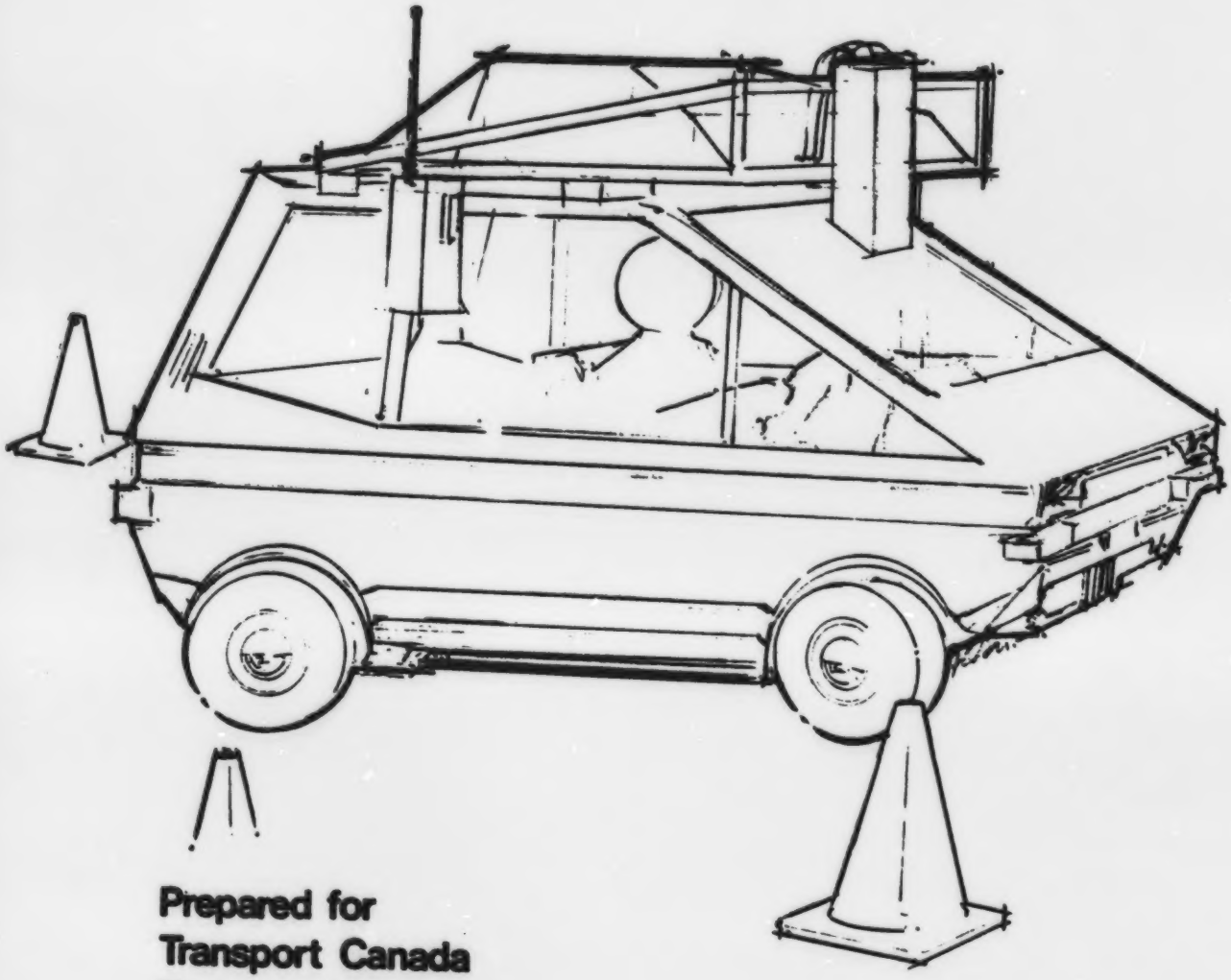
An Ergonomic Evaluation of The Elswick Envoy

TP 4939E



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AN ERGONOMIC EVALUATION OF THE ELSWICK ENVOY

by

West Park Research,
University of Toronto

September 1983

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17. Abstract

This report describes the ergonomic evaluation of the Elswick Envoy, a small automobile designed for use by disabled people in wheelchairs. The main advantage of such a vehicle would appear to be for the person who finds it physically difficult or impossible to transfer from a wheelchair to a conventional automobile, and then stow the wheelchair in the car. The Envoy has a kneeling feature which allows direct access by a ramp through a rear door; the disabled person then operates the vehicle whilst seated in the wheelchair. The evaluation, which involved a comprehensive series of tasks and measurements, was carried out by a team of specialist observers on a sample of five disabled drivers. Results indicate that many of the physical actions required to operate the Envoy are beyond the capability of the very population which could benefit most from its wheelchair-access design and, indeed, of those who presently drive their own standard automobiles that have been converted for use by the addition of hand controls. In brief, safe use of the vehicle in its present form would be restricted to people having strong upper limb function with normal control and good trunk musculature.

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17. Résumé

Ce rapport rend compte de l'évaluation ergonomique de l'Elswick Envoy, petit véhicule destiné au transport des personnes en fauteuil roulant. Ce véhicule est supposé convenir à toute personne dans l'incapacité totale ou partielle de passer de son fauteuil au siège d'une voiture ordinaire et ensuite de ranger le fauteuil après l'avoir hissé à l'intérieur. La suspension arrière de l'Envoy s'abaisse pour faciliter l'accès par la porte arrière à l'aide d'une rampe. La personne, assise dans le fauteuil roulant, conduit elle-même la voiture. Le programme d'évaluation ergonomique prévoyait un échantillonnage de cinq sujets qui devaient exécuter une série de mouvements devant des observateurs qualifiés. Les résultats ont montré qu'un grand nombre des mouvements exigés pour conduire la voiture dépassent les possibilités de la population visée et même celles des sujets qui conduisent déjà une voiture adaptée comportant des commandes manuelles. Tel quel, ce véhicule ne saurait être utilisé en toute sécurité que par des personnes dont la motricité et le contrôle musculaire ne posent aucun problème ni au niveau des membres supérieurs ni à celui du tronc lui-même.

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SUMMARY

The Elswick Envoy is a small automobile designed for use by disabled people in wheelchairs. It features a suspension lowering system with a rear door and ramp to provide direct access. The disabled person operates the vehicle whilst seated in the wheelchair. Two small, sideways mounted seats facing each other are provided for passengers behind the driver.

The ergonomics of this vehicle were evaluated by a team of specialist observers on a sample of five disabled drivers. This report describes the observations of the researchers and of the subjects.

The flexibility, balance, strength, range of motion and fine finger dexterity required to enter, exit, and operate the vehicle are considerable. The main advantage of a car such as the Elswick Envoy would appear to be for the person who finds it physically difficult or impossible to transfer from his wheelchair to a conventional automobile and then to stow the wheelchair. Yet the physical actions required to operate the Envoy are at present not even suitable for many of those who do drive their own standard automobiles that have been converted for their use by the addition of hand controls. Safe use of the vehicle in its present form would be restricted to people having strong upper limb function with normal control and good trunk musculature.

There is probably a significant market for an accessible, fuel efficient vehicle for disabled persons unable to transfer into a conventional automobile and unable to afford a van with a wheelchair lift and hand controls. There may also be a market for a small vehicle as an alternative to converted cars and vans for disabled persons who would prefer more convenient access, easier parking, and lower operating costs for short trips, especially in the urban environment.

When asked on a questionnaire administered following the testing whether they would buy the vehicle if it were available in Canada at a reasonable price, none of the subjects replied positively. Although the concept of the vehicle is attractive, there are many features of the design requiring improvement.

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THE ELSWICK ENVOY

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Chapter 1 BACKGROUND

1.1 Discussion

In 1983 the Road Safety Directorate of Transport Canada brought two Elswick Envoy automobiles from Britain to test against Canadian safety standards. These tests were to include an ergonomic evaluation of the vehicle in order to determine its efficiency as a personal vehicle for Canadian disabled drivers. This part of the study was assigned to the Transportation Development Centre which contracted it to West Park Research.

West Park Research (WPR) developed a protocol for ergonomic assessment of the vehicle covering operations and/or features related to:

- getting in and out of the vehicle
- use of controls
- manoeuverability
- seating
- visibility
- and general suitability for Canadian disabled drivers.

This protocol was then administered by WPR to five subjects with varying degrees of upper-limb strength. This report is based upon the results of those tests. Also included are interpretations and recommendations regarding design features necessary or desirable in a personal vehicle for disabled drivers in Canada.

The objective of this study has remained consistent with Transport Canada's overall objective to remove transportation barriers to Canada's physically disabled.

Chapter 2 A DESCRIPTION OF THE VOLUNTEER TEST SUBJECTS

2.1 Introduction

In Canada there, is no reliable statistical information available to use to predict the number of potential users of this type of vehicle. Systems Approach Consultants Limited estimated the number of transportation-handicapped individuals in Canada to be 43,000 (1). Their calculation was based on a detailed survey performed in the United States and on Canadian census data. As the incidence of transportation-handicapped was found to increase with age, this number will rise with the growing number of elderly citizens in Canada.

The contract for this project called for the evaluation of the vehicle to be done using five wheelchair-bound volunteers with varying degrees of upper limb function. This chapter describes the relevant physical characteristics of these subjects.

Two consent forms were signed by each subject prior to testing: one for participation in the evaluation of the Elswick Envoy, the other for photography.

2.2 Measurement Techniques

Physical assessment and anthropometric measurements were conducted by the same investigators for all of the subjects.

Gross grasp was measured using a STOELTING Co; Kilogram Dynamometer. Hand grip measures were taken as the average of two tries in each hand, alternating left and right measurements. The arm was not supported against the body or side of the wheelchair during testing. Pinch grip was estimated from the same dynamometer (which was adjusted to the minumum handle size upon which the thumb pad and index pad could be pinched). Pinch grip measures were the average of two tries on each hand.

Sitting balance and transfer mobility were investigated. Standard musculoskeletal and neurological screening of the upper limb, lower limb and trunk for sensory and motor deficits, and limited range of motion were conducted (2,3,4).

For each subject eight body dimensions were measured to define the range of body sizes. A Siber Hegner free-standing anthropometer and sliding calipers were used. Standard anthropometric definitions (5) were adapted for the subject seated in the test wheelchair. Seat cushions were used if desired and the footpedals were properly adjusted.
The body dimensions recorded for each of the subjects were:

sitting height,
eye height - erect posture,
- relaxed posture,
thumb-tip reach,
buttock-knee length,
thigh clearance
hand length, and
functional hand span.

Seat cushion dimensions and footpedal measurements were also recorded for each subject.

2.3 Subject Characteristics

The subjects who participated in the evaluation of the Elswick Envoy represented a broad age range (27-63 years), almost equal sex distribution, and varied levels of disability. All of the subjects were independent in their activities of daily living and were capable of independent driving in their own hand controlled cars. The subjects were licenced drivers, excepting subject 5 who had a learner's permit.

The body dimensions of the five subjects represented a broad range of percentiles within the North American driver population. Sitting height, eye height, and hand dimensions of the subjects varied to include 5th to 95th percentile measures. Thumb-tip reach was limited and ranged below the 50th percentile for functional arm reach. Buttock-knee length of the subjects also varied from 1st to 50th percentile, limiting observation of possible interference between the steering column and the driver's knees.

The most significant findings are shown in Table 1.

Subject #	1	2	3	4	5
Sex	M	F	M	M	F
Age	39	39	33	27	63
Disabled Driving(Yr)	7	1	1	6	less than 1
Present Car Modification	H/Control	H/Control Steering Spinner	H/Control Steering Spinner	H/Control Steering Spinner P/B Ext. 4.5"cushion	H/Control Steering Spinner P/B Ext.
Disability	Paraplegia (T7,8 comp)	Multiple Sclerosis	Quadri-plegia (C6,7)	Spina Bifida (T10)	Bilateral A/K Amp.
Body Weight (Kg)	87	50	73	43	66
Dominance	Right	Right	Right	Right	Right
Gross Grasp (Percentile)*	85-100	0-10	0	10-35	80-95
Pinch (R) (L) (N)**	80 90	15 20	0 0	70 40	45 35
Spasticity(UL) (LL)	N Y	N Y	N Y	N N	N N
Sitting Balance	support required	support required	support required	support required	good
Transfer	indep	indep	indep	indep	indep
Sensory Deficit(UL)	N	Y	Y	N	N
Motor Deficit(UL)	N	Y	Y	N	N
Joint Deficit (UL)	N	N	Y	N	N

* Jette M. Standardized tests of fitness in occupational health: Fitness Assessment Report. Canadian Public Health Association, 1977.

** Instrument error at 0-100 N is ± 20%

TABLE 1 Subject Characteristics

Chapter 3 THE ELSWICK WHEELCHAIR

3.1 Introduction

The Elswick Envoy is designed for use by a disabled driver seated in a specially designed wheelchair that is provided with the vehicle. The restraint system will not function with other wheelchairs (without considerable modification). This report, therefore, begins with an examination of the wheelchair.

3.2 Method

The five subjects were observed using the wheelchair throughout the vehicle testing period. Problems were noted by members of the evaluation team. The findings are a compilation of those notes and of the reponses of the subjects to a questionnaire administered after the test sequence.

3.3 Observations

The observations are summarized in table 2.

The wheelchair was not suitable for all subjects in terms of comfort and size.

There was a wide range of preferences in style and size of personal wheelchair. Subject five used an anti-tip device for safety while subjects one and four normally used very light-weight highly maneuverable chairs. Subject five never used footrests whereas armrests were never used by subject four.

The clearance from the ground was measured as 47 mm under the front restraint attachment point and 68 mm under the rear restraint bar. This would present difficulties on uneven surfaces. Some of the subjects felt that maneuverability was further compromised by the weight of the chair however this was found to be 20 kg which is only 1 kg more than a commonly used standard wheelchair (Everest & Jennings - "Starliner").

DESCRIPTION OF PARAMETER	VERY GOOD	ACC	NOT ACC	PROBLEMS AND COMMENTS (by subject number)
I. WHEELCHAIR ASSESSMENT				
1. steering	1	2	1	4-awkward due to weight of chair-has difficulty doing sharp turns
2. propulsion		1	4	2&4-wheels are too far back 2-stiff 3-poor grip necessitated the use of gloves
3. maneuverability		3	2	all subjects found that the front wheels did not turn easily
4. braking	2	1	2	4-normally does not use brakes; this chair is excellant because the brakes keep clear when wheeling 2-concern for unusual position of levers, too low, each brake applied seperately, must look to find brakes 3-backwards operation of levers considered to be unsafe for emergency stop on hills.
5. stability	5			
6. seat				
height	1		4	subjects 1,2,3,4-seat too low
slope	2	2	1	
depth				
width	1	2	2	subjects 1 & 5 -too narrow
cushion			4	(5-does not use one ever)

7. backrest				
length	1	1	1	
slope to horizontal	1	1	1	3-felt uneasy when leaning backwards
back to seat angle	1	1	1	
push bar			5	1,4-no handles to put things on, encourages others to push, distracts vision, restricts maneuverability around back of the chair 3-cannot hook arm around the pushbar for balance 5-had to put arm under the pushbar to reach back
8. armrests				
length		1		
width		1	1	
adjustability		1	3	3-trouble removing pin 5-difficult to remove and replace 2-found trunk balance difficult when removing arm rests therefore used belt around trunk for test (this might have been somewhat better if the seat height was correct, as his knees were well off the seat)
9. footrests				
size	1	1	2	2,3-need longer footrests but would bottom out on the ground if they were long enough therefore seat must be raised 3-prefers to drive with feet on floor
position	1	1	2	
adjustability	1	1	2	2/3-found footrest difficult to clear away
ground clearance		1	3	
10. weight			2	3-too heavy and cumbersone looking 4-too heavy in relation to position of wheels with respect to centre of gravity-difficult to tip up on rear wheels

TABLE 2 Observations of the suitability of the special wheelchair

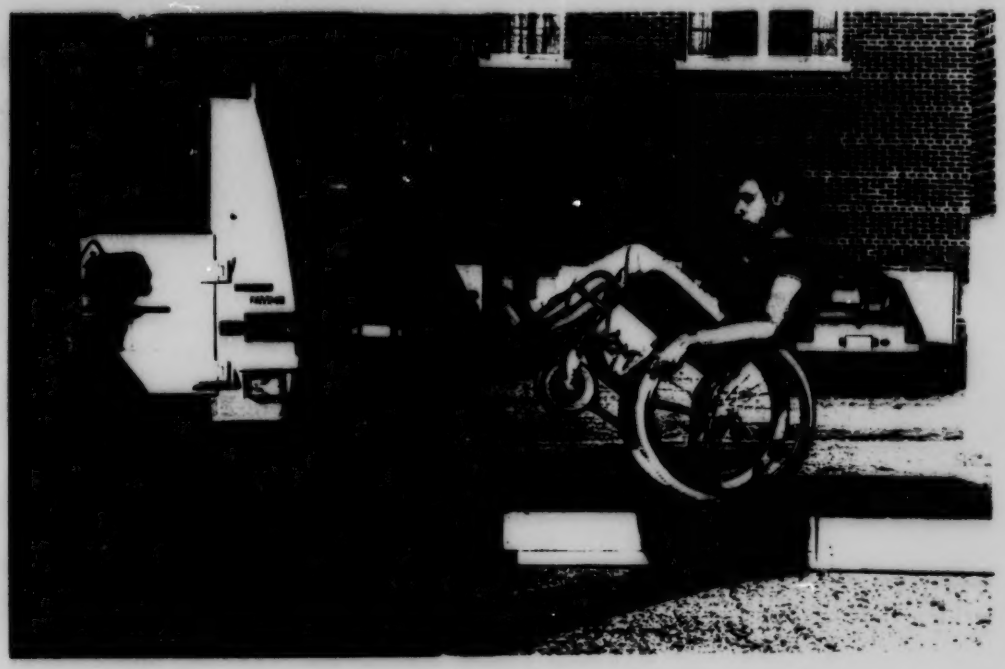

Figure 1 A subject with good upper limb function found the chair difficult to balance because of the backwards displaced axle. Note the reduced ground clearance under the rear restraint bar

The pushbar on the back of the wheelchair obstructed vision and made reaching backwards for tasks, such as closing the car door, more difficult. This was particularly a problem for the shorter drivers. Disabled persons who have poor trunk balance sometimes hook one arm over the push handle on a standard wheelchair in order to provide stability when leaning to the opposite side. The pushbar prevented one subject from using this technique. The pushbar was also disliked because subjects felt that it would encourage others to push the chair.

Most subjects were concerned that this chair was not foldable for ease of transportation in other situations. With the exception of subject four, the general appearance of the chair was felt to be cumbersome.

The general conclusion by all subjects was that they would prefer to use their own wheelchairs to drive from instead of the one supplied.

3.4 Recommendations

1. Redesign the wheelchair restraint mechanism so that it may be adapted to accommodate different chairs.

2. If a special chair is to be offered as an option with the vehicle, then an improved design should be developed.

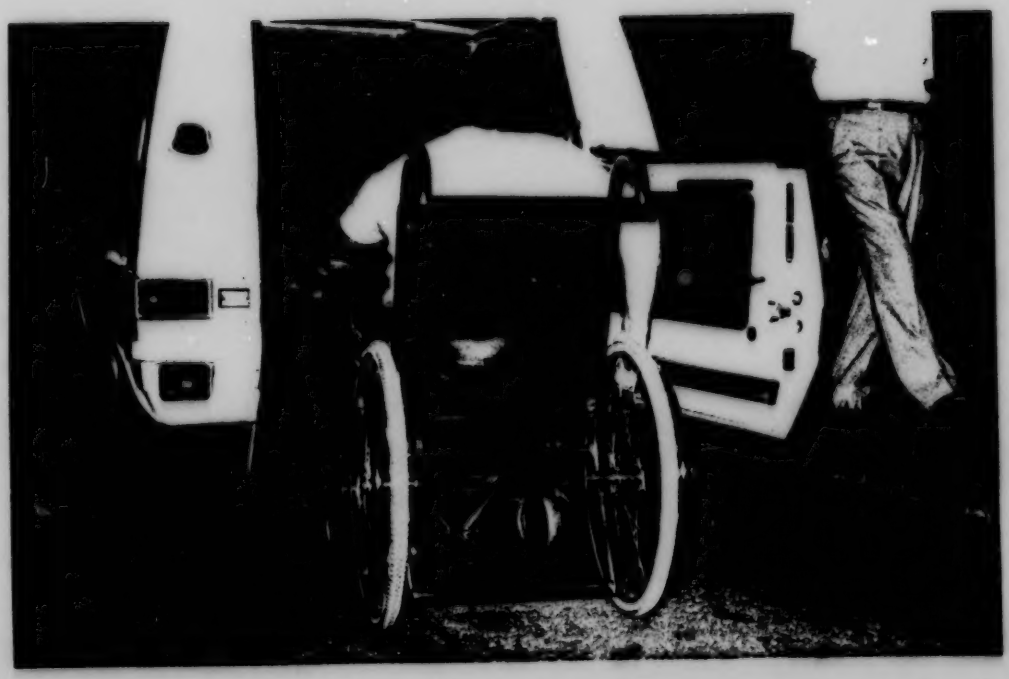

Figure 2 Rear view of the Elswick Wheelchair.

Chapter 4 INGRESS AND EGRESS

4.1 Introduction

The Elswick Envoy has two doors, one on the left side and one on the rear. The car is equipped with a system that allows it to be lowered closer to the ground at the back to reduce the effort required to propel a wheelchair up the ramp through the rear door.

4.2 Method

Before each trial began the subjects were guided through a complete ingress and egress of the vehicle in order for them to become familiar with the routine. During the evaluation the subjects were observed and prompted if necessary. The evaluator then made note of the ease with which each step was performed and recorded any problems or observations . Simultaneously another evaluator recorded the time to complete each step.

The evaluation of ingress and egress on a grade was done during the driving test. The subject was asked to park near the curb on the grade(1:12), then leave and reenter. Again the evaluator made note of any problems and prompted as necessary to maintain a smooth routine.

To evaluate transverse parking, the vehicle was backed up to a 16 cm curb and then the subject was asked to enter and exit the vehicle.

The loading of parcels was evaluated using a plastic grocery bag containing assorted groceries. The subject was instructed on a step by step procedure for loading the parcel in the side door along the ledge away from the wheelchair tracks. Instructions were then given for entrance through the rear door and eventual placement of the parcel on the same ledge.

4.3 Observations

Listings of the individual steps in the evaluation are given in Table 3 to 6. The number of subjects who performed the particular step with ease or with difficulty or who found it impossible is also tabulated. The average time and

the range of times to complete each step is found in the TIME column if that particular section was timed. Also note that some subjects were not evaluated for all tasks due to the nature of their disability, or subject discomfort. For that reason some lines in the tables do not show results for all 5 subjects.

Figure 3 Difficulty opening the door

Because of poor finger dexterity and motor skills, subject 3 had difficulty placing the key in the lock and turning it to unlock the doors; otherwise this presented no problem to the other subjects. After opening the door latch most subjects had no difficulty swinging the door open, however subject 2, because of poor upper limb strength, had difficulty swinging the door hard enough to make it stay open.

INGRESS	WITH EASE	WITH DIFF	NOT POSS	TIME (s) AVG	TIME (s) RANGE
1. descend from curb		2	3	17	17
2. approach vehicle	5			8	7-9
3. unlock rear door	4	1		20	2-52
4. open door latch	5			13	4-36
5. lower ramp	4	1		13	5-28
6. lower car (switch)	5			12	4-17
7. ascend ramp	3	2		20	4-43
8. raise ramp	5			22	17-32
9. close rear door	4	1		14	5-33
10. move to front	3	1	1	14	7-20
11. lock wh/ch tiedown	3	2		17	7-37
12. lock wh/ch brakes	5			5	2-6
13. lower passenger seats	4	1		19	7-33
14. raise car (switch)	5			12	9-17
15. remove both armrests	3	1		25	16-40
16. apply seat belt	4	1		28	17-56
17. do push-up	5			6	3-11
TOTAL FOR INGRESS	AVG. 232 sec. RANGE 120-404 sec.				

Note: Some frequencies do not add up to 5 since some subjects were not evaluated for all sections. This was due in part to the nature of their disabilities and in part to personal comfort.

TABLE 3 Sequence for Ingress

EGRESS	WITH EASE	WITH DIFF	NOT POSS	TIME (s) AVG	TIME (s) RANGE
1. release seat belt	5			3	2-5
2. attach armrests		4		48	38-61
3. raise passenger seats	3	2		12	4-15
4. release wh/ch brakes	5			8	5-10
5. disengage wh/ch tiedown	4	1		8	7-10
6. lower car (switch)	5			12	7-21
7. move to rear	5			7	4-13
8. open rear door	3	2		16	6-27
9. lower ramp (lever)	5			8	6-9
10. descend ramp	3	2		19	4-49
11. raise car	5			13	9-18
12. raise ramp	5			9	3-16
13. close rear door	5			7	4-11
14. lock rear door	4	1		26	6-59
15. ascend curb			5	--	----
TOTALS FOR EGRESS	AVG. 180 sec. RANGE 72-269 sec.				

TABLE 4 Sequence for Egress

PARCEL LOADING (not timed)	WITH EASE	WITH DIFF	NOT POSS
1. descend from curb (w/groc)			3
2. approach side door	5		
3. unlock side door	4	1	
4. open side door	3	2	
5. place groceries	5		
6. close side door	5		
7. approach rear door	5		
8. unlock rear door	4	1	
9. open door latch	4	1	
10. lower ramp	4	1	
11. lower car	5		
12. ascend ramp (w/groc)	3	1	
13. raise ramp	3		
14. close rear door	3		
15. move to front	3		
16. place groceries	4		

TABLE 5 Sequence for Parcel Loading

TRANSVERSE PARKING		WITH EASE	WITH DIFF	NOT POSS
1. approach vehicle	4			
2. unlock rear door	4			
3. open door latch	4			
4. lower ramp	4			
5. ascend ramp	3	1		
6. raise ramp	4			
7. close rear door	4			
8. depart parking space	4			
9. park transversely	3	1		
10. move to rear	5			
11. open rear door	5			
12. lower ramp (lever)	4	1		
13. maneuver wh/ch out	4	1		
14. raise ramp	4			
15. close rear door	4			
16. lock rear door	4			

For TRANSVERSE PARKING	INGRESS	AVG.	128 sec.
		RANGE	70-240 sec.
	EGRESS	AVG.	158 sec.
		RANGE	55-240 sec.

TABLE 6 Sequence for Ingress and Egress with Transverse Parking

Figure 4 With the rear door open the ramp was then swung down. Motor and sensory deficits in subject 2 caused her to lose balance while leaning forward to push the ramp to the ground or leaning to lift it.

Figure 5 The bilateral transfemoral amputee (5) who had good upper limb strength was able to lean her left hand against the door frame for stability.

After the ramp was lowered the subjects then proceeded into the vehicle. Three subjects found that there was insufficient clearance between the passenger seat handles and the rims on the wheelchair. They subsequently skinned knuckles and jammed fingers when entering and exiting the vehicle. The other two subjects either used wheel rims alone or a combination of rims and the passenger seat handles. In moving towards the front all drivers were hindered by the two rear wheelchair tiedown brackets on the floor. The footrests on the chair invariably got caught. One subject was able to do a "wheelie" over the obstruction but for the remainder the footrests had to be adjusted. Raising and lowering the ramp with the lever was an easy task for all.

All subjects were able to close the rear door from the inside but it was obvious that subject 2 was using maximal effort. It was also noted that the door handle was at the limit of subject 5's full reach. If a conscious effort was made to extend the folding rear door handle prior to entry then it was found to interfere with ascension of the ramp.

With the ramp raised and the rear door closed the drivers then attempted to engage the wheelchair in the tiedown mechanism. This presented difficulty for three of the subjects. There were two problem areas. The first was lining up the wheelchair bracket with the floor clamping mechanism. This had to be done visually so that females with skirts had to rearrange their clothing and paraplegics who could not abduct their legs had to manually spread them in order to have an adequate view below. The other difficulty was engaging the wheelchair so that it was squarely in the tiedown brackets. This required fairly accurate alignment which was found to be quite difficult and often required several attempts to complete the task.

Prior to fastening the seat belt the armrests were removed. This presented no major difficulties but there were some problems replacing the armrests . Wide subjects, drivers with skirts, and weak subjects had trouble finding the armrest holes on the wheelchair and then had difficulty getting the armrests in the holes. Subject 2 tended to lose her balance while leaning to find the holes. Applying the seat belt was difficult for subject 3. Because of poor motor skills and dexterity he found it hard to pull the belt through the necessary range of motion and then target and push the buckle home. Subject 4 was particularly short and found that the seat belt went across his neck and tended to bind.

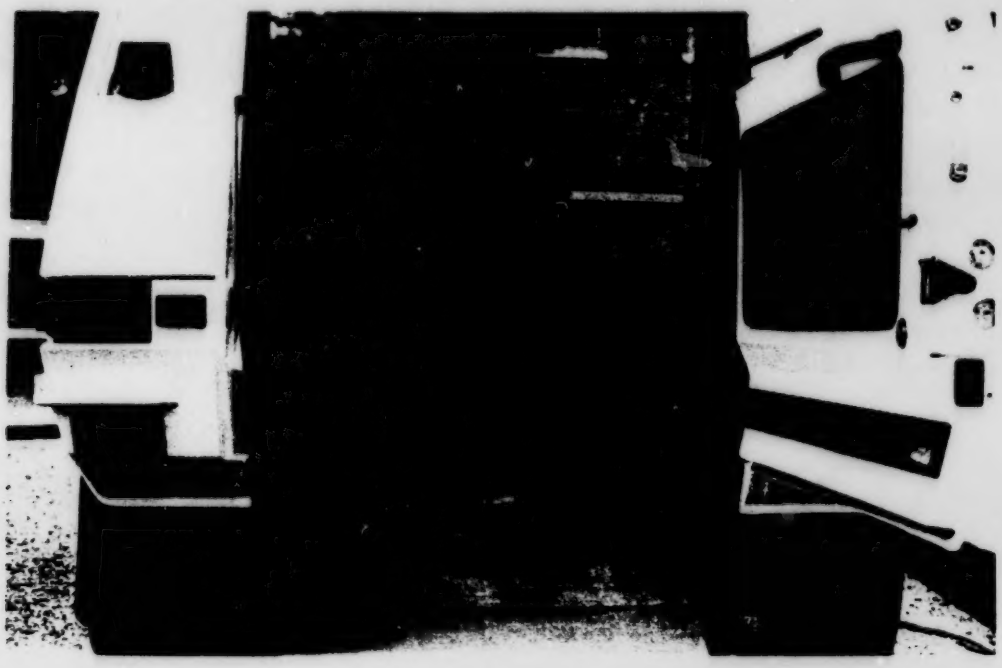

Figure 6 Showing obstructions created by restraint system on the floor

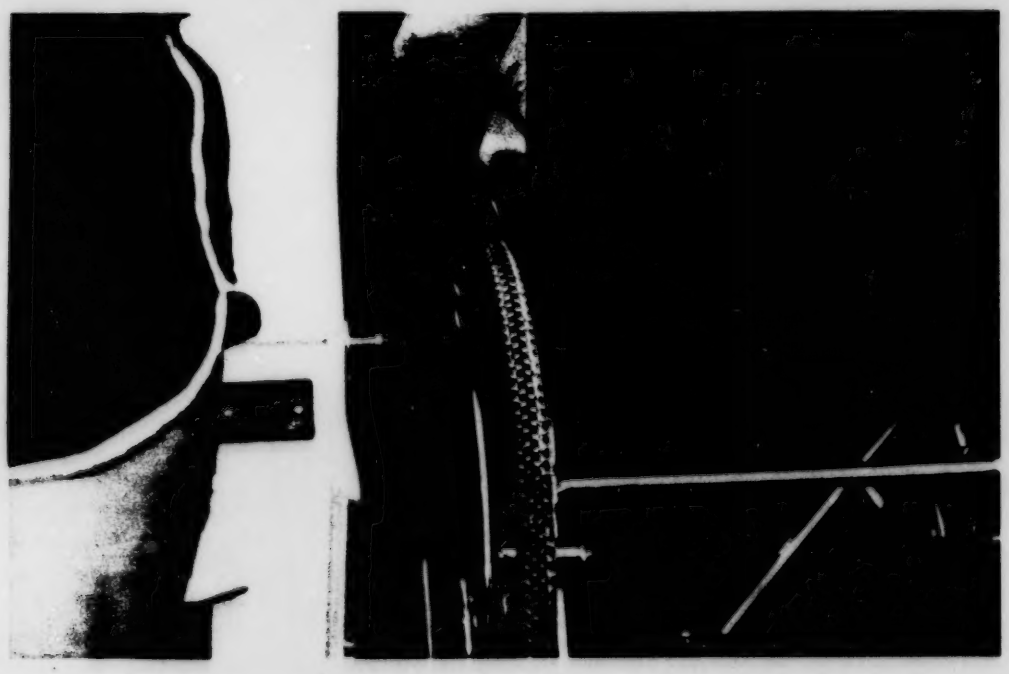

Figure 7 Interference between hand rim and passenger seat handle

Figure 8 Door handle is difficult to reach for average sized subject.

Figure 9 Seat belt and backrest cause difficulties for shorter drivers

Figure 10 Shorter driver finds raising the passenger seat impossible

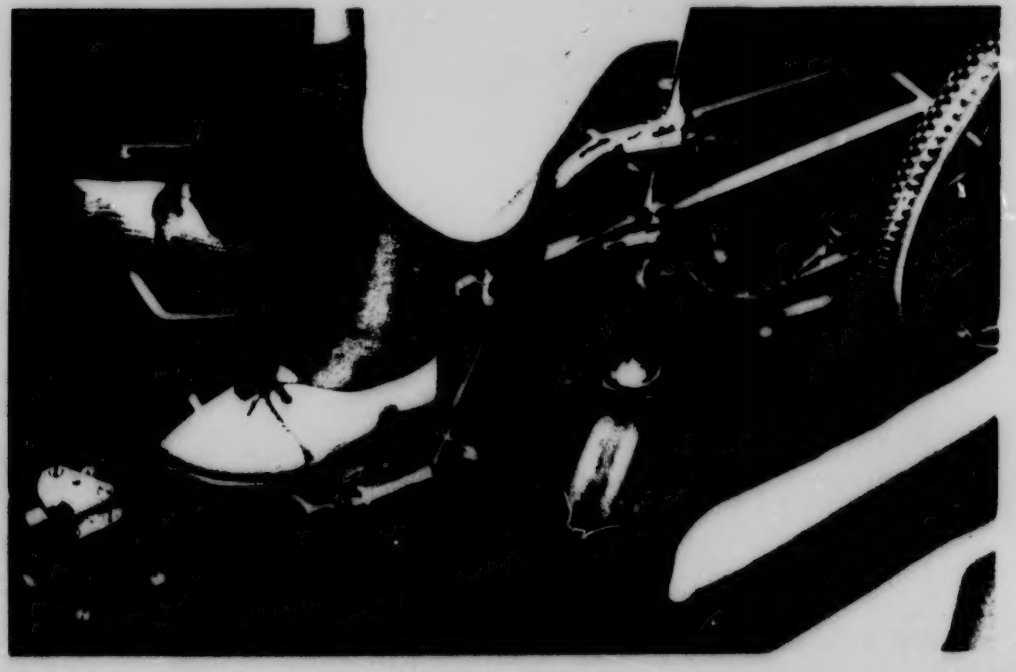

Figure 11 Swivel of front wheel is blocked by floor hump.

The subjects had no difficulty with the first six steps in egress (Table 4) other than those previously mentioned (attaching armsrests, pushbar interference with raising/lowering passenger seats). Moving to the rear was often hampered by the front wheels of the wheelchair which were not able to complete a full 180 degree swivel because of the hump in the center of the floor. The subjects were forced to stop halfway and manipulate the chair so that the wheels could swivel.

Loading parcels into the side door of the car did not present major problems. All subjects were able to swing the door open enough to place the groceries on the ledge inside the side door and then close the door. Of course, each subject had a particular method of carrying the package depending on their special ability. Some carried the package in their lap and one driver (5) mentioned that she normally has a special side platform on her wheelchair for this purpose. Subjects 3 and 5 carried the package in their hand and so had difficulty loading from the rear door because of the need to use two hands to ascend the ramp.

Figure 12 Loading groceries into the Elswick

No special problems were encountered with ingress and egress from the transverse parking position or on the incline. The weaker subjects found that when parked facing uphill moving to the front of the vehicle and engaging the wheelchair restraint was much easier if the car was raised immediately after ascending the ramp. Four subjects had difficulty judging the vehicle's proximity to the curb

especially while transverse parking and, in fact, two drivers hit the curb.

4.4 Discussion

An important rationale for developing a vehicle such as the Envoy is to make transferring from a wheelchair to a conventional automobile unnecessary and therefore make independent transportation available to people who are physically unable to do a transfer. The car would be of less value if it was merely a slightly more convenient method of transportation for the population which already can use modified conventional automobiles. Therefore we must keep in mind that this vehicle should fulfill the needs of people who are too weak or spastic to transfer into a car and then manipulate their wheelchair into the vehicle.

The results of the evaluation of ingress and egress suggest that the concept of the vehicle is sound but the design of the vehicle still presents some problems for the population for which it was interfaced.

The locks, as was seen with subject 3, are difficult for a person lacking fine finger dexterity and we can assume that there will be many such people who will want to drive as driving does not require fine digital motor skill.

The rear door opening was no problem for the subjects with full upper limb strength, but subject 2 was using full power to open and close the doors. Subject 2 will have difficulty using a conventional automobile because of the strength required to haul the wheelchair into the car after transferring. Her experience with the Envoy suggests that the same disability hampering her use of a conventional automobile will also hamper her use of the Envoy.

When entering the vehicle, the wheelchair is aligned using the handrails provided by the raised passenger seats. The height of the handrails allows the pushrims of the wheelchair to jam under the handrail, potentially trapping the drivers fingers. The limited clearance between the handrail forces the subjects to pull themselves forward without use of the wheelchair handrims. To accommodate the full range of body sizes, especially when wearing winter clothing, a wider chair would sometimes be necessary, further compounding the existing space restrictions.

The mechanism securing the wheelchair into the vehicle has some serious drawbacks. The rear tiedown brackets projecting up from the floor interfere with the passage of the wheelchair footrests. Users who cannot balance on the rear wheelchair wheels alone, must raise the footpedals to clear the wheelchair retention system. This forces the driver into a poor body position for both health and comfort.

Figure 13 One of the subjects transfering to his own standard car which has been converted by the addition of hand controls.

Figure 14 Pulling in the wheelchair during transfer

The wheelchair retention system could be improved by providing more visual cues to target the correct position or by developing some mechanism that is self aligning. Some users are not able to visually check the alignment by looking between their legs.

Removal of the armrest prior to attachment of the seatbelt removes lateral stability and arm support for quadriplegic drivers. Many drivers also prefer to position their feet on the floor to improve stability. Subjects with limited balance were using the steering wheel to provide the necessary support when driving. Although using a cushion would help overcome visibility problems experienced by shorter drivers it might add to the stability problem.

4.5 Recommendations

1. Incorporate a mechanism to enable the user to raise and lower the ramp from outside the vehicle without having to balance and lean forward or touch the dirty ramp.

2. Improve the accessibility of the door opening and closing mechanism from within the vehicle.

3. Relocate or alter the handles on the passenger seats in order to remove their potential as an obstruction.

4. Relocate or alter the wheelchair retention system in order to simplify its operation and remove its potential as an obstruction.

5. Add a car-elevating switch located in the rear of the vehicle so that the driver can raise and lower the car as soon as he enters and so do less work against gravity while moving forward in the car.

6. Provide a self-aligning feature to guide the wheelchair into the restraint system.

7. Incorporate a seat belt restraint system that does not require removal of the armrests.

8. Improve the design of the seat belt clasp and buckle so that less fine motor skill is required.

9. Consider an indicating system for judging distance to curbs.

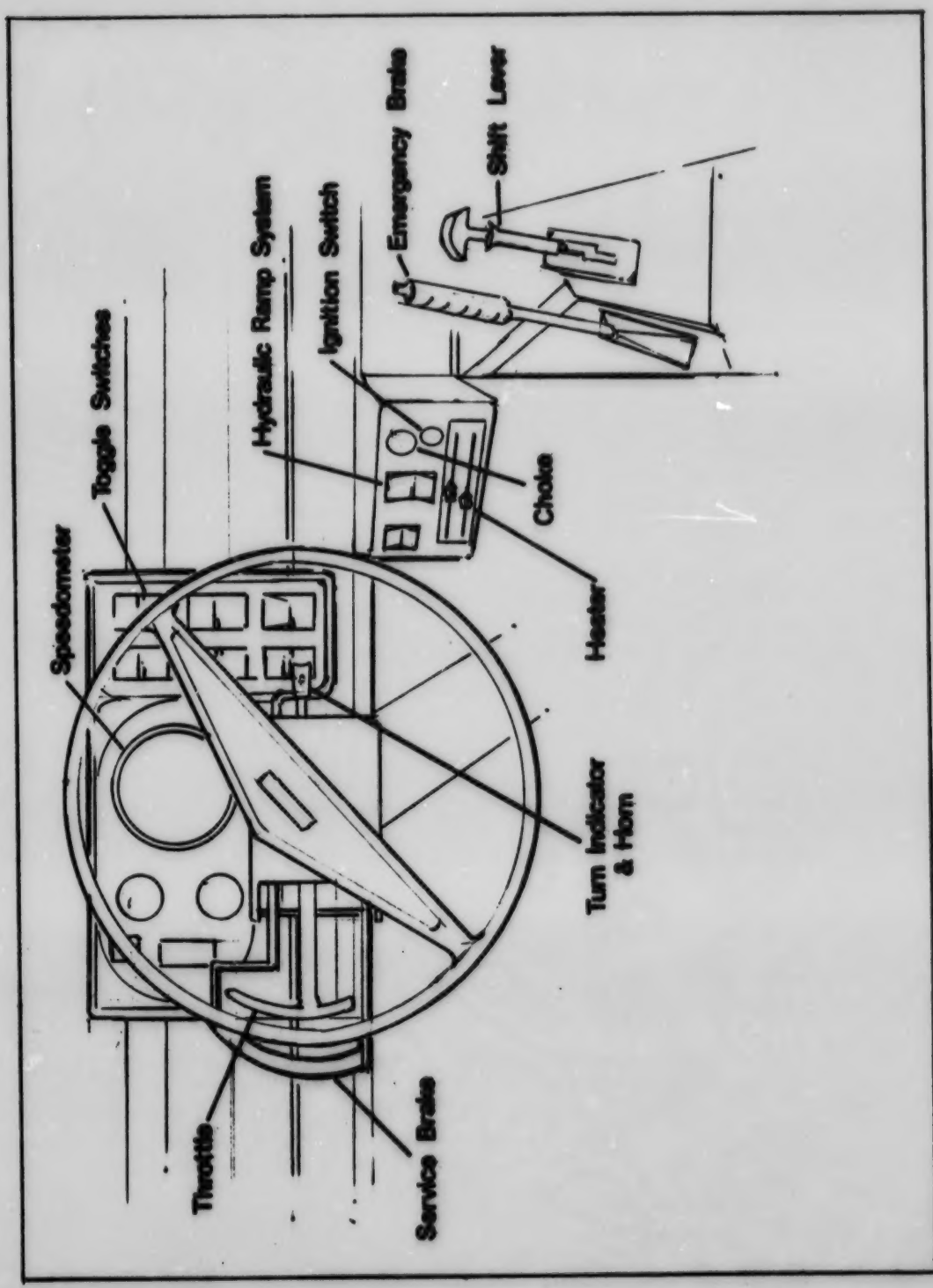

Figure 15 The control panel

5.1 Protocol

Evaluation of the vehicle controls was carried out by assigned observers recording observations as each subject was asked to activate the control in a static situation and again while going through the simulated road test. All subjects had an opportunity to contribute their findings by responding to a questionnaire at the completion of the test run.

5.2 Observations

5.2.1 Throttle

Mounted on the left side of the steering column the throttle is a small T-shaped handle which is activated by the fingers pulling up on the handle towards the steering wheel. Most drivers used the hand as a bridge between the thumb on the steering wheel and fingers on the throttle, making easier the sustained pulling action required.

5.2.2 Service Brake

The service brake is a larger handle outside the throttle also mounted on the left side of the steering column and set in action by a strong pull upwards toward the steering wheel. The hand is generally held in the same position as described above, and the fingers move from throttle to brake as required.

The distance between the brake control and steering wheel represented a near maximum hand span for one subject. The position of the brake meant that the fingers rather than the palm sensed the brake pressure.

The hand controls of the Elswick Envoy were unfamiliar to all subjects used in our trials. The single lever "push-pull" or "right angle push" controls are more common in North America.

The subjects used in our study found the throttle easier to use than the brake, but found the sustained pulling action extremely tiring, and did not like moving their hand from one handle to another. Subjects were generally more comfortable with the North American type controls.

Figure 16 Operating the service brake.

5.2.3 Parking Brake

The hand brake is a pull-back lever which operates mechanically on the rear wheels only and is mounted to the right of the driver on his side of the gear selector. To release the brake, the level is pulled back slightly, the button on the end of the lever is depressed, and the lever is pushed forward.

Three out of five subjects were unable to depress the button while at the same time pushing the lever forward. One person could set the brake but could not release it.

5.2.4 Steering Wheel

Steering was found to be heavy and stiff by all subjects, sometimes requiring two hands to complete expected manoeuvres. Forces required to turn the wheel are documented in chapter 7 of this report. Fatigue and balance disturbance were encountered when turning the wheel sharply, or over a prolonged period.

The steering wheel was found to be small for a comfortable hand grasp. However, the diameter of the steering wheel was found to accept commercially available steering spinners for a variety of hand grasps e.g. palm grip, tri-pin, bi-pin, or steering knob.

5.2.5 Gear Shift

The automatic transmission incorporates a fluid torque converter coupled to a hydraulically operated four-speed and reverse gearbox. The driver can either use the system as a fully automatic transmission or as a manual gearbox with all four forward gears and reverse. The selector lever is mounted on the right of the driving position.

A reverse stop on the gear lever quadrant and a spring-loaded slide on the selector lever prevents inadvertent selection of reverse gear when the car is being driven forwards, particularly when "manual" down-changes are made. To engage reverse the driver must lift the slide and move the lever into the "R" position.

Select "R" for reverse
"N" for neutral
"1" for first gear
"2" for second gear
"3" for third gear
"D" for automatic drive using all forward gears.

Both observers and drivers commented on the difficulty encountered when trying to lift and push the lever at the same time to engage reverse. Several subjects had to let go of the service brake in order to accomplish this. They also found the reach for reverse beyond comfortable and safe range. One commented on the roughness of the gear selector and in one situation the gear shift got stuck between gears.

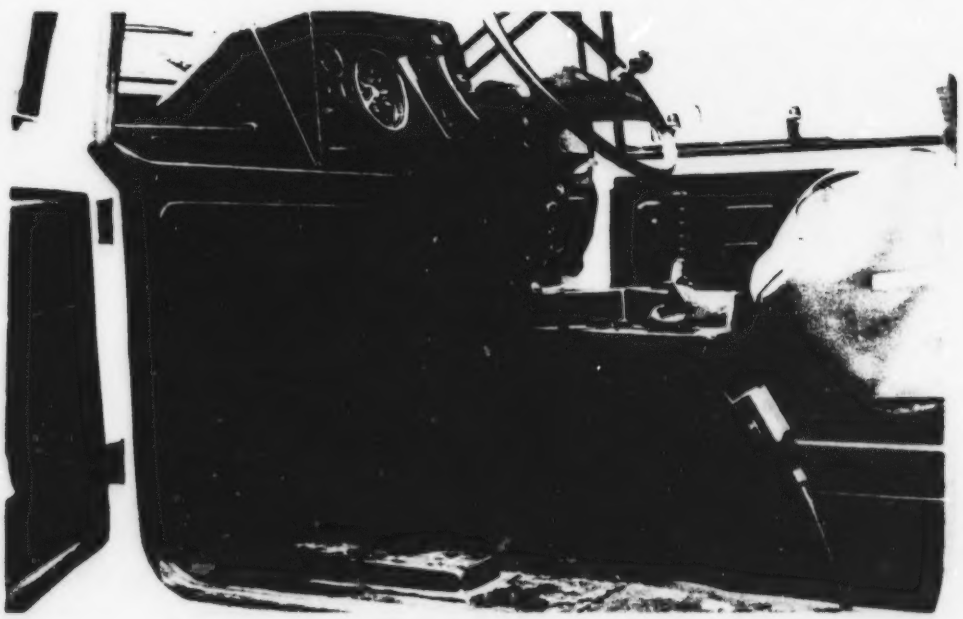

Figure 17 Gear shift and parking brake are to the right of the driver

5.2.6 Choke

The choke is pulled out to the required position and locked by turning the knob one quarter turn. To reposition, the knob is turned anti-clockwise one quarter turn and pushed in. Hand function required is a fine two finger thumb pinch grasp, first to pull and then to turn.

Observers rated the ease of operation of the choke acceptable or better. The only person who demonstrated any real difficulty was the subject with spinal cord injury whose finger dexterity was impaired. He was able to pinch the knob between his second and third knuckles to pull, but the turning motion was very difficult.

5.2.7 Ignition

To switch on, the key is turned to the first position; further movement against spring resitance operates the starter motor.

The switch is located to the right of the steering wheel in a position visible and within easy reach for all subjects. One driver had difficulty but he generally uses a key extension handle and this could easily be added to the Envoy key.

5.2.8 Direction Indicators

A lever on the right side of the steering column is moved upwards for turning left and downwards for turning right. The signal self-cancels when the steering wheel returns to the straight ahead position.

The reach from steering spinner to the lever behind requires a full stretch of the right hand to grasp the lever handle. One subject had to release the hand on the steering wheel in order to reach the indicators as the distance exceeded her normal grasp. One of the other drivers commented that although the lever is manageable for him, its movement was awkward because the wide panel across the steering wheel occluded vision of the lever behind.

5.2.9 Lights

Parking - side, tail and license plate lights are turned on by moving a switch to its first position

Headlights - the second position of the above switch turns on the headlights

Headlight Dipper - with headlights switched on, the direction indicator lever is moved forward to use the main beams, and returned to mid-position to dip the beams

Flasher - the lever is pulled back to flash the headlights

Interior Lights - the inside lights are linked to door operated courtesy switches, but can also be switched on/off by using switches on the lamp directly

The toggle switches were all situated within easy reach, and all were easy to operate.

5.2.10 Horn

The horn is activated by pressing the end of the turn signal lever with the right hand.

5.2.11 Mirror Adjustment

Interior: The stem of the interior mirror may be moved easily to any position within the limits of the base-safe socker. This requires elevation of the shoulder and extension of the arm and hand above head level, as well as grasp of the mirror for adjustment.

Exterior: The heads of the right and left exterior mirrors are adjustable from the drivers seat when the windows are open.

Figure 18 Adjusting an exterior mirror

The drivers all found both types of mirrors acceptable or very good; one observer commented the outside mirrors would be more effective if a little larger. A long reach is required to make the outside adjustments.

5.2.12 Windows

The side windows may be partially opened by depressing the window catch and sliding either the front or back glass to the desired position. This provides a total maximum opening area of 1350cm^2, limiting ventilation, especially for rear passengers.

Windows may be locked in the closed position by ensuring that the window catch locking plungers are engaged.

The fine hand grasp required for moving the windows was a problem for one subject. Spinal-cord injured persons whose normal body regulatory controls have been disrupted often require air conditioning. One subject required frequent interuptions because of shortness of breath, fatigue, and dehydration.

5.2.13 Miscellaneous Controls

Windshield wiper/washer
Rear window heater
Hazard warning
Heater/blower
Rear fog guard

All of the above were activated by easy to use toggle switches.

5.2.14 Washer Fluid And Oil Level

Since the majority of Canadian gas stations are self-service it is worth noting that the front opening hood would make the washer fluid and oil inaccessible to many disabled drivers. The high position of the gas filler cap (110cm) is also of concern.

CONTROLS	VERY GOOD	ACC	NOT ACC	REASONS(IF NOT (ACCEPTABLE)
1. throttle	1	4		disliked moving hand from throttle to brake. action required fatiguing jerky at low speed would like push action better
2. brakes service		1	4	sustained holding of brake very tiring hand sore after a few minutes could not hold on hill should be push action
parking	1	1	3	unable to depress button very tough; not always able to release impossible
3. steering wheel		2	1	hard to turn, stiff felt like cranking handle
spinner			2	too small
4. choke	2	2	1	could pull, but not turn
5. ignition switch	4	1		
6. gear shift		1	4	hard to lift up & forward at same time rough "teeth" difficult to put into reverse; lost control of service brake would like "park"position

7. turn indicators	3	2	had to remove hand from steering wheel panel across wheel blocks lever
8. lights			
parking lights	5		easy to operate, but didn't like so many switches
headlights	5		
high beam	5		
flasher	5		
interior light	5		
9. horn	5		
10. windshield wiper	5		
washer	5		
11. mirror adjustment			
interior	5		
right	5		
left	5		
12. opening windows			
right	5		
left	5		
13. miscellaneous			
brake check	5		
rear window heater	5		
rear fogguard	5		
hazard warning	5		
heater/blower	5		

TABLE 7 Controls Drivers Comments

CONTROLS	VERY GOOD	ACC	NOT ACC	PEASONS (IF NOT) (ACCEPTABLE)
1. throttle	4	1		
2. brakes				
service	2	2	1	very stiff requires constant pressure pull action wring for emergency
parking	1	1	3	stiff; unable to push button and pull lever at same time
3. steering wheel	2	1	1	steering heavy & stiff driver tends to lose balance sometimes needed two hands
spinner	2	1		spinner knob small
4. choke	3	1		
5. ignition switch	4	1		ignition lock shifted
6. gear shift	1	1	1	difficulty pulling up and moving lever at same time quite a stretch to reach reverse gear selector stuck in between gears
7. turn indicators	4			almost at maximum grasp some had to release hand on wheel

8. lights			
parking lights	5		
headlights	5		
high beam	5		
flasher	5		
interior light	5		
9. horn	5		
10. windshield wiper	5		
washer	5		
11. mirror adjustment			
interior	3		one lost balance reaching outside window
right	2	2	need wide arm span
left	2	2	outside mirrors could be larger
12. windows			
opening/closing	4	1	one had difficulty with latches because of reduced finger grasp
13. miscellaneous			
brake check	5		
rear window heater	5		
rear fogguard	5		
hazard warning	5		
heater/blower	5		

TABLE 8 Controls Observers Comments

5.3 Suggested Modifications

5.3.1 Hand Controls

It would be desirable to have the ability to substitute alternative hand controls of choice: for right or left hand, push pull, push/twist or right angle push.

Clear labelling and/or a diagram of the hand control operation is essential for anyone other than the owner needing to move the car e.g. car mechanic, car jockey, or friend offering assistance.

5.3.2 Parking Brake

This should require less effort to operate.

5.3.3 Steering

Power steering is an essential modification if the vehicle is to be driven by someone with any upper limb or trunk muscle weakness. A wheel should be used that is capable of accepting a wider variety of steering spinners so that the steering aid can be more easily matched to individual needs. An adjustable tilt steering wheel would be a valuable improvement.

5.3.4 Gear Selector

This should be mounted closer to driver and/or position reverse near to driver.

5.3.5 Choke

This should be automatic.

5.3.6 Dashboard

All switches on the dash should be illuminated for night driving.

5.3.7 Air Conditioning

This often is a must for persons with disturbed body temperature regulation.

Chapter 6 DRIVEABILITY

6.1 Protocol

Vehicle license and insurance restrictions for the Elswick Envoy during our evaluation limited testing to the use of a driving range on private property. Critical manoeuvre areas were marked by pylons set at 3 m for land widths, at a 9 m lateral opening for a lane change, and a representative parking space was marked as 2.4 m wide and 6 m long. Traffic lights were simulated by a time keeper with a flag.

In order to test the vehicle and the drivers ability to handle the car in a predetermined space relative to average daily driving encounters, a test route was set up, and subjects were instructed to perform the following tasks:

depart from parallel park
left turn
right turn
straightaway with emergency stop (accelerate to 50 km/h)
U-turn
high speed straightaway
lateral manoeuvre (at 40km/h, shift to next lane and back)
traffic lights (holding vehicle with service brake maximum
42 seconds
duration)
sharp left turn
downhill park (exit and enter vehicle)
turn about
uphill park (exit and enter vehicle)
traffic light (30 second stop followed by right turn)
parallel park
transverse park (exit via rear door onto sidewalk)

6.2 Observations

6.2.1 Driving Conditions

Testing commenced at the same time of the day for five consecutive days (18:00 hours). The weather was clear and the road surface was dry on each of the test days. The temperature (18:00 hours, Toronto Airport) ranged from 23°C-25°C. The sunset time on the first test day was 20:14 hours and on the fifth day it was 20:08 hours. On most occasions driving was completed by 21:00 hours but on 2

occasions it was past 22:00 before the driving tests were finished.

6.2.2 Depart from Parallel Park

The drivers found the gear selector difficult to operate because it required two movements, lifting the slide, and moving the lever at once. Reverse gear was almost at the extent of their safe reach. Three out of five subjects found they could not release the hand brake without assistance.

Heavy steering plus the effort required to operate the hand controls resulted in slow uncoordinated movements. In a real traffic situation a second eye scan by the driver would have been required when merging with another lane, and this would not have been possible.

6.2.3 Left Turn

In order to signal a left turn the steering (right) hand had to leave the wheel at the same time as the left hand had to use the brake; this left the steering wheel unmanned. Turning was performed too slowly for safety.

Figure 19 Note that both hands are on the wheel in order to provide sufficient torque to accomplish this turn; the hand controls have been abandoned.

6.2.4 Right Turn

Generally subjects completed the turn too wide because of stiffness of the steering; once again acceleration was too slow for safety.

All turns were adversely affected by three factors: heavy steering, the force required to operate the service brake, and the need to let go of the steering wheel in order to use the signals. The vehicle was therefore driven at a rate of speed judged to be too slow for normal traffic conditions.

6.2.5 Emergency Stop

Each of the subjects was able to reach a speed of 50 km/h on the straighaway before coming to a sudden stop. The vehicle brakes worked very well to halt the car. Inside the wheelchair shifted sideways, disengaging the tie-down system and causing the buzzer to sound. The driver inevitably lost his balance and required assistance to prepare for driving again. On one occasion the passenger seat back dislodged pulling out the anchor screws (heavier screws were installed).

6.2.6 U-Turn

All subjects were able to perform a U-turn at a suitable speed but on completion of the turn had to stop to correct body balance.

6.2.7 "High Speed" Straightaway

All subjects were able to accelerate to a speed of 40-50 km/h for a short time but an even speed was difficult to maintain on the throttle for all but one.

6.2.8 Lateral Manoeuvre

None of the drivers was able to maintain the required speed of 40 km/h to simulate an evasive manoeuvre and return. Three subjects took over the steering wheel with both hands, but the speed then dropped to less than 20 km/h. The two other subjects lost steering control and crossed over the road centre.

Figure 20 Emergency stop causes car to pitch forward frequently resulting in loss of the driver's balance

6.2.9 Traffic Lights

In both traffic light simulations, all drivers experienced difficulty in holding the service brake for a prolonged period (30s). As fatigue set in, the car began to creep forward, and the left and right turns immediately following were not well executed.

6.2.10 Sharp Left Turn

Once again, subjects had difficulty in maintaining expected turning speed. With vehicle slowdown affecting the natural cornering of the vehicle, the tendency was to cut the left turn badly, while at the same time drivers expressed fear of losing their balance.

6.2.11 Downhill Park

Subjects found it awkward to set the wheels into the curb whilst controlling the service brake. Their hands became tired from the heavy pull on the service brake required to prevent the car form rolling downhill while at the same time setting the parking brake.

6.1.12 Turnabout

For those subjects with any upper extremity impairment the range and strength required to engage reverse gear while pulling up on the service brake made this a difficult task. Their view while backing around the corner was occluded by the rear seat passenger.

6.2.13 Parallel Park (6 m space)

Manoeuvres were performed slowly owing to the heavy steering. All subjects felt that such a small vehicle should be easy to park in this much space, but did not find it so. By this time fatigue was also a major factor.

6.2.14 Transverse Park

Figure 21 Shorter driver finds judging the distance to the curb particularly difficult.

The transverse parking test was administered in order to evaluate the manufacturer's claim that this parking attitude could be used by owners of Elswicks instead of more common parking attitudes . The instruction manual stated that the vehicle was designed with this possibility in mind.

Parking the car perpendicularly to the curb required careful estimation of distance. Concern was expressed about visibility, particularly when one cannot poke one's head through an open window or open the side door for better visibility.

If the curb is higher than the vehicle then the ramp will not be flush with the footpath unless there is sufficient space between the back of the car and the curb. This causes the front of the car to protrude beyond the customary 2.4m distance form the curb.

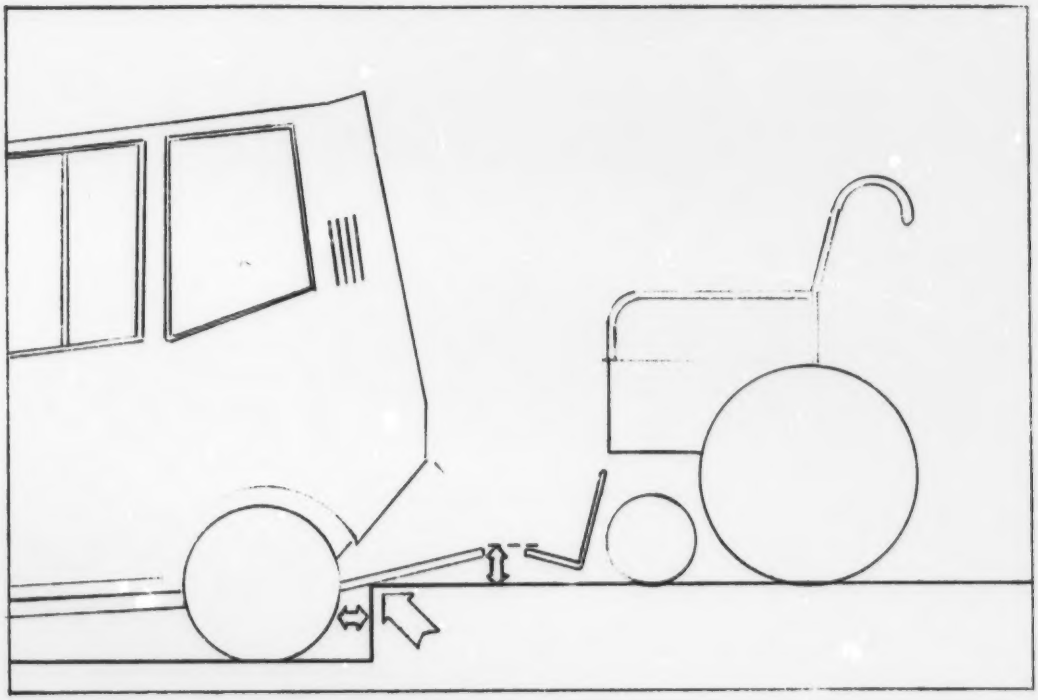

Figure 22 The diagram illustrates the effect of parking too close to a high curb.

Figure 23 The car parked close to the curb.

6.3 Discussion

The Elswick Envoy is a compact, apparently stable vehicle with some good handling qualities. Poor design of the interface between man and machine prevented this car from being driven easily and safely by our disabled subjects.

Chapter 7 VEHICLE SAFETY

7.1 Introduction

Many aspects of vehicle safety were beyond the scope of this study. Only those aspects pertaining to ergonomic features of design were addressed. Some of these items have been described in earlier chapters on controls and driveability.

Subjects were asked their overall impression of the safety of the vehicle. Three subjects rated it "not acceptable", one "acceptable" if "told by authorities" and one response was in the third category of "very good".

7.2 Restraint Systems

Figure 24 The seatbelt system

The drivers seatbelt assembly should be assessed in conjunction with the wheelchair retention system, using Society of Automotive Engineers (SAE) standards (6,7). The seatbelt assembly used in this vehicle has been recommended as suitable for transport of all wheelchair users (8).

However our observations indicated that the upper torso restraint was in direct contact with the neck of shorter drivers, compromising both safety and comfort. Headrests were desired by only one driver.

Visibility is restricted for drivers with limited strength and balance. Turning the head to look over the shoulder when reversing is difficult if both hands are on the controls. Larger mirrors are needed. The positioning of passengers with respect to the driver increases the size of the blind sectors.

There should be a locking device to prevent turning on the ignition before the car is raised. Starting the car when lowered might pose a fire hazard with the tail pipe resting in dry grass. On several occasions subjects or researchers began to drive the vehicle without remembering to raise it. The existing motor does not adequately raise the vehicle with adult passengers in the car. Even with the car fully raised the ground clearance is only 9 cm with a 55 kg driver and we wonder whether this might cause safety problems with winter snow.

Ventilation and heating are valid concerns for safe driving in the Canadian climate. With the large window area, air conditioning must be an option for those requiring it.

Passengers have a limited sense of security in the vehicle. There is little protection from rear impact. There are no passenger seatbelts provided and the sideways orientation of the seating is not optimal in emergency stops. The bar on the back of the wheelchair presents a potential hazard for unrestrained passengers.

Emergency situations may necessitate removal of the driver from the vehicle. This would prove very difficult even for those familiar with the car. The wheelchair retention system should be clearly identified to allow removal of both driver and chair.

7.3 Miscellaneous Safety Issues

Adequate space is provided for addition of a fire extinguisher which should be placed within reach of the driver.

It was noted that with the engine fast idling on choke it became almost impossible to stop the car in reverse after two or three applications of the brakes. This nearly caused an accident when a researcher was reversing out of the garage having just started the engine.

Chapter 8 PHYSICAL CHARACTERISTICS OF THE VEHICLE

8.1 Visual Field

Figures 25, 26, and 27 show the visual field plotted for a 50th percentile adult.

8.2 Forces Required to Operate the Vehicle

The forces required to operate the various driving controls and to gain access to and from the vehicle are listed in Table 9. The forces were measured using strain gauge load cells: [Interface, Model SM 100] for tensile forces and [Sensotec, Model 13] for compressive forces. Both load cells were calibrated by loading the device with known weights.

The force requirements must be related to the capabilities of the disabled driver. In addition to the magnitude of the required force, other factors must be considered: (1) the direction of the required force, (2) the length of time that the force must be applied, and (3) the required position and orientation of the arm and hand. All of these factors are discussed in length in the section dealing with controls. However, two important conclusions are immediately evident: (1) the forces required to operate the parking brake are unacceptably high, even for drivers having no neuro-motor deficits, and (2) the relatively large forces required to operate the service brake and throttle may lead to fatigue in situations requiring long-duration use.

8.3 Steering Wheel Torque

The torque required to turn the steering wheel was measured: (1) with the car stationary and (2) with the car moving through a series of "figure-8" turns (at minimum possible turning radius, vehicle speed approximately 15 km/h). The moving tests were conducted with and without a passenger, driving forward and in reverse. The values obtained for the Elswick Envoy were compared with the torques required to drive a conventional manual-steering car (1983 Toyota Tercel: rack-and-pinion steering, front-wheel drive) and a conventional power-steering car (1978 Chevrolet Malibu stationwagon: rear-wheel drive). These comparisons were made in an attempt to obtain a "ball-park" quantification of the Elswick steering requirements.

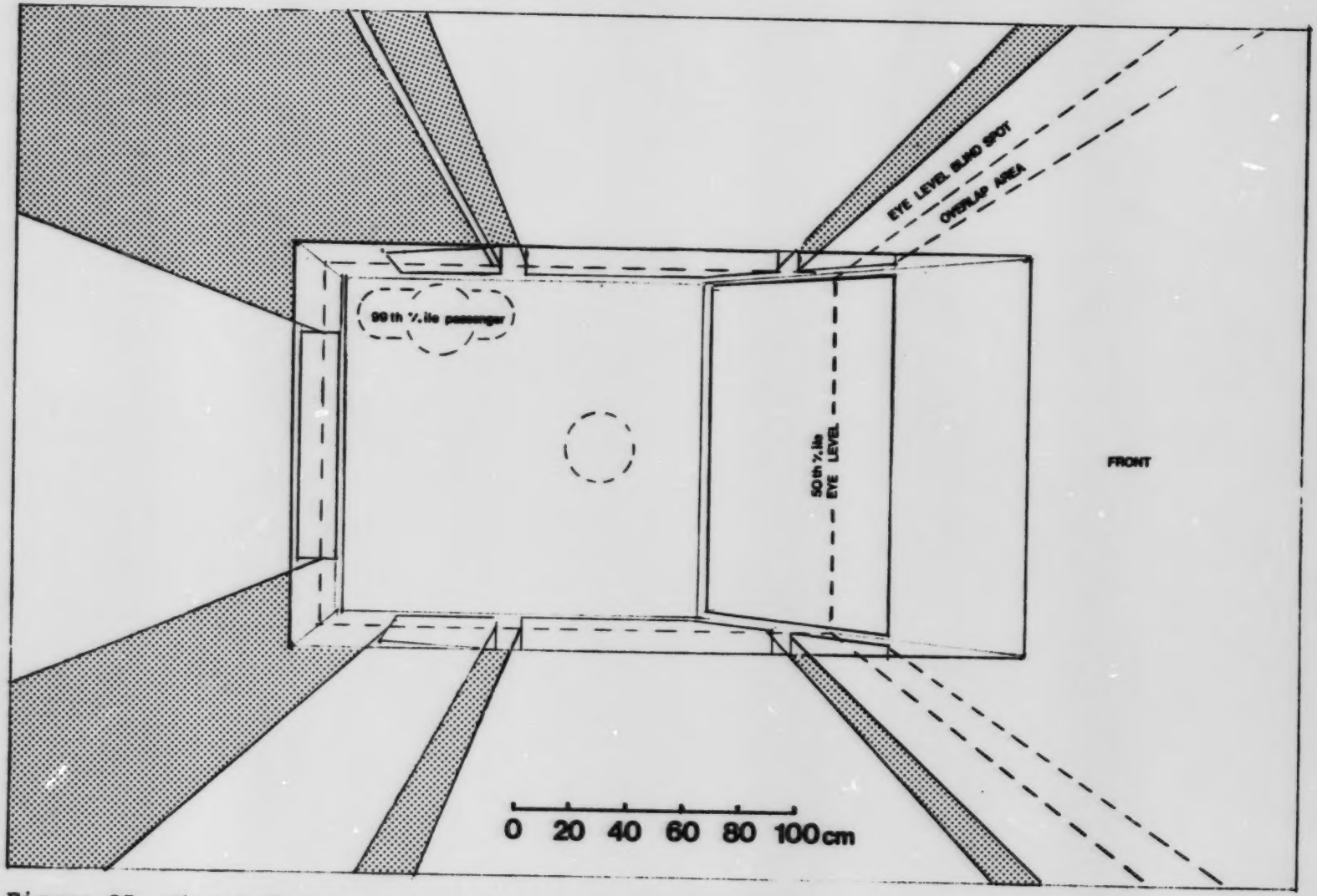

Figure 25 Visual field: perimeter of vehicle (top view)

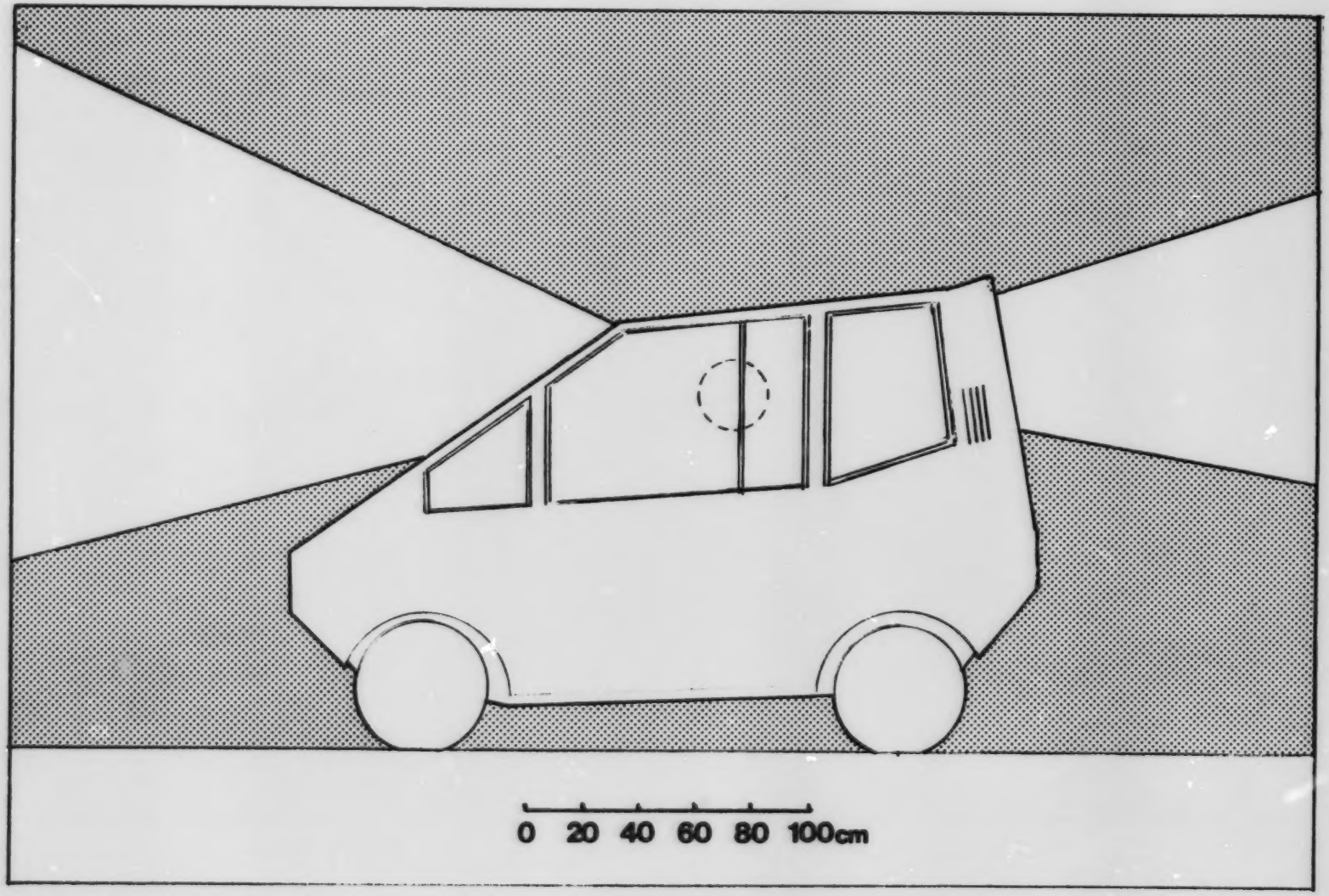

Figure 26 Visual field: forward and backward (side view)

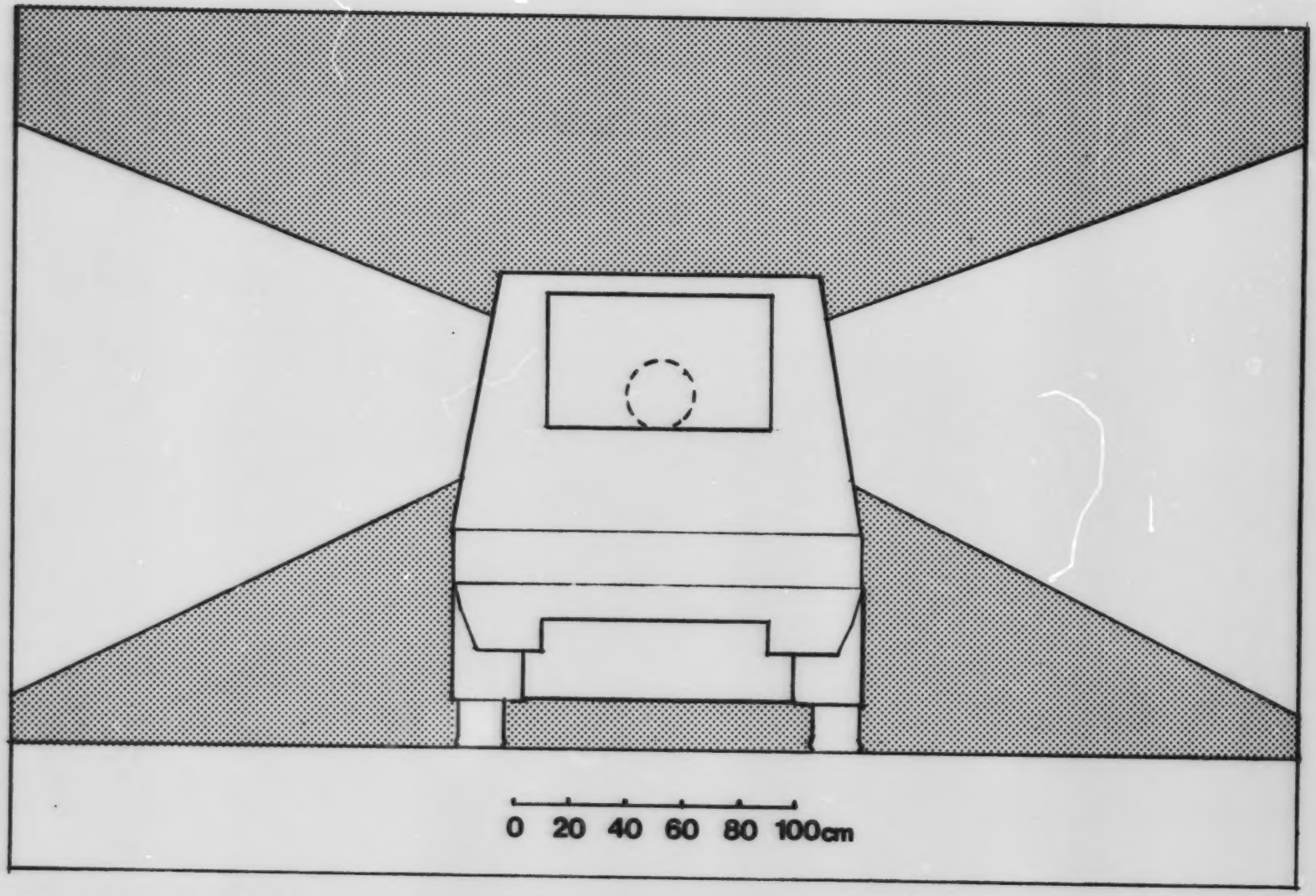

Figure 27 Visual field: to each side (end view)

Operation	Force Required
1. Service Brake:	
(1) keep car stationary (engine at fast idle)	47.0 N
(2) apply full brake (measured with car stationary)	118. N
2. Parking Brake:	
(1) set parking brake	173. N
(2) pull back on lever to release brake	116. N
(3) release parking brake (using the button)	
(i) while pulling back on lever	78.0 N
(ii) without pulling back on lever	135. N
3. Throttle (accelerator):	
(1) to start acceleration of the engine	29.4 N
(2) apply full throttle	44.1 N
4. Gear Shift	44.1 N
5. Typical Control Toggle (e.g. headlights)	16.8 N
6. Horn	13.8 N
7. Vent Lever	31.7 N
8. Ingress/Egress:	
(1) open rear door latch	73.5 N
(2) operate toggle to raise/lower car (time req'd to raise car = 6.0 seconds)	30.4 N
(3) raise ramp (using lever)	77.9 N
(4) close rear door (using inside handle)	77.9 N
(6) release wh/ch from tie-down (using pull handle)	60.3 N
(7) raise passenger seat	38.9 N
(8) open rear door (using inside handle)	38.6 N

TABLE 9 - Force Requirements

	Elswick Envoy	Conventional Manual-Steered Car(Toyota Tercel)	Conventional Power-Steered Car(Chevrolet Malibu)
(1) peak torque req'd to turn wheels with car stationary	27.6 Nm	29.4 Nm	4.0 Nm
(2) average torque req'd during representative turn	4.4 Nm	2.7 Nm	2.0 Nm
(3) peak torque req'd during representative turn	10.3 Nm	8.8 Nm	4.8 Nm

TABLE 10 - Steering Wheel Torque Requirements

The torques were measured using a strain gauge torsional load cell (Lebow 2133-105). The load cell was mounted between the steering wheel of the vehicle and a second steering wheel (used to steer the vehicle during the measurements). The load cell was calibrated by loading the device with known weights at known moment arms.

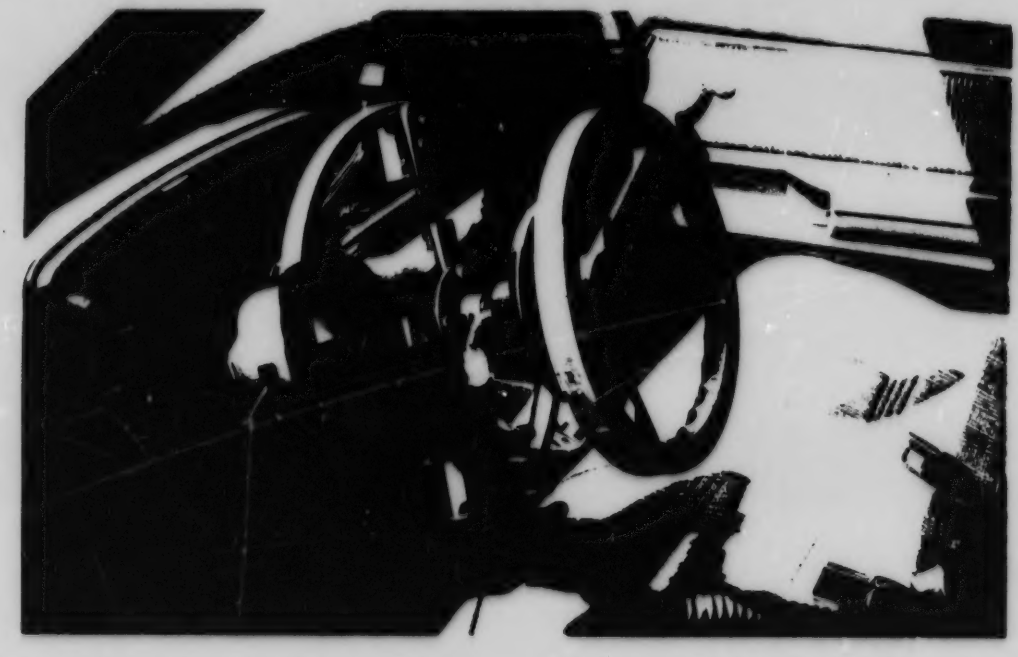

Figure 28 Strain gauge torsional load cell in place

Typical results are shown below. The torques obtained while driving with a passenger and in reverse did not differ appreciably from the no-passenger, forward-driving results, and are therefore not reported. For each vehicle a representative turn was selected and, for this turn, the average and peak torques were calculated. These values are listed in Table 10. The table also lists the peak torque required to turn the wheels when the vehicles were stationary.

The Elswick Envoy and the conventional manual-steered car showed similar requirements for peak torque (under both stationary and moving test conditions). However, the Elswick did appear to require significantly greater levels of average torque when the vehicle was moving. In comparison to the power-steered vehicle, the Elswick clearly required substantially greater levels of torque, under all test conditions. These results suggest that a power-steering option would be essential for users with limited upper arm strength.

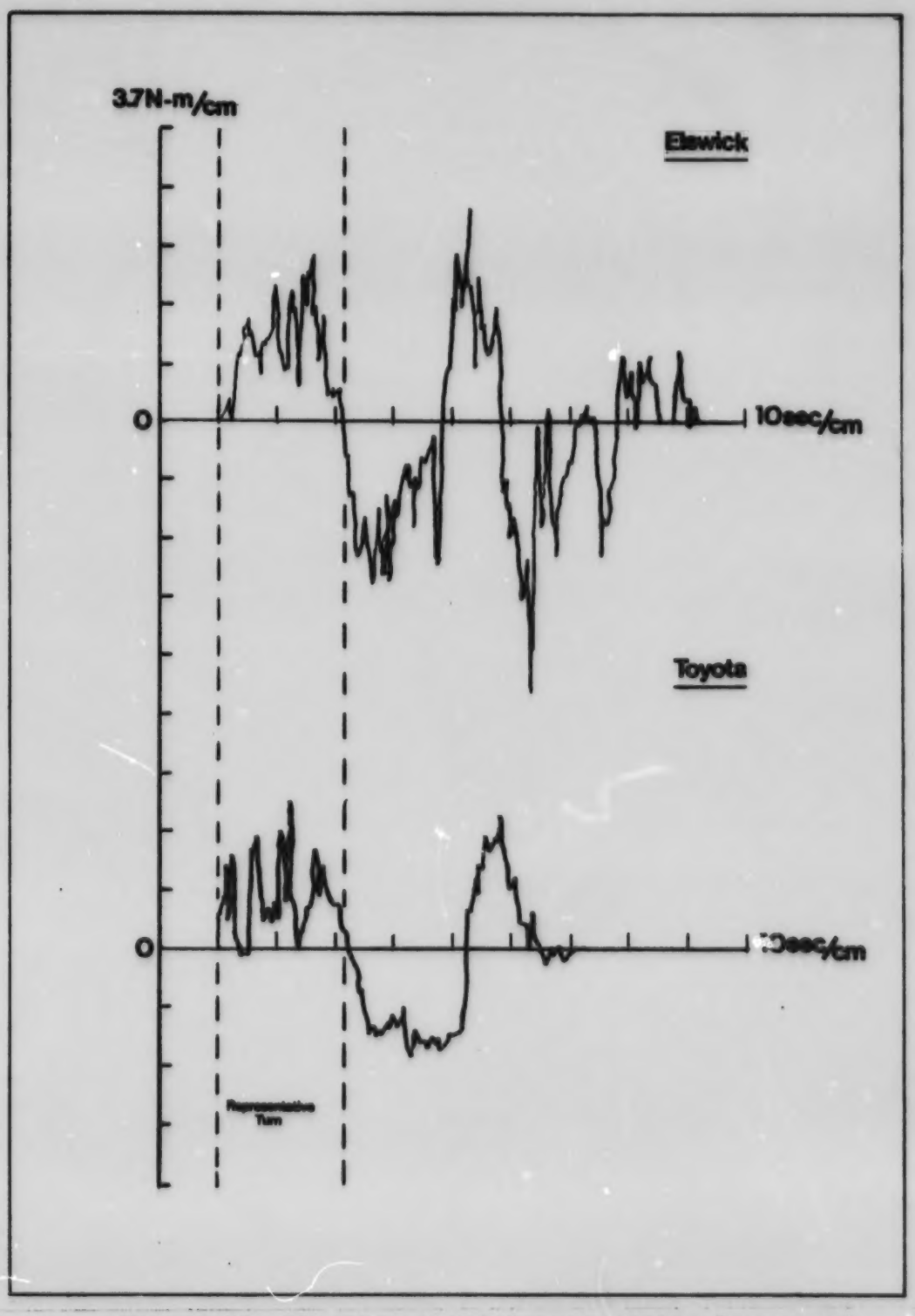

Figure 29 Steering wheel torque during low speed turning manoeuvres

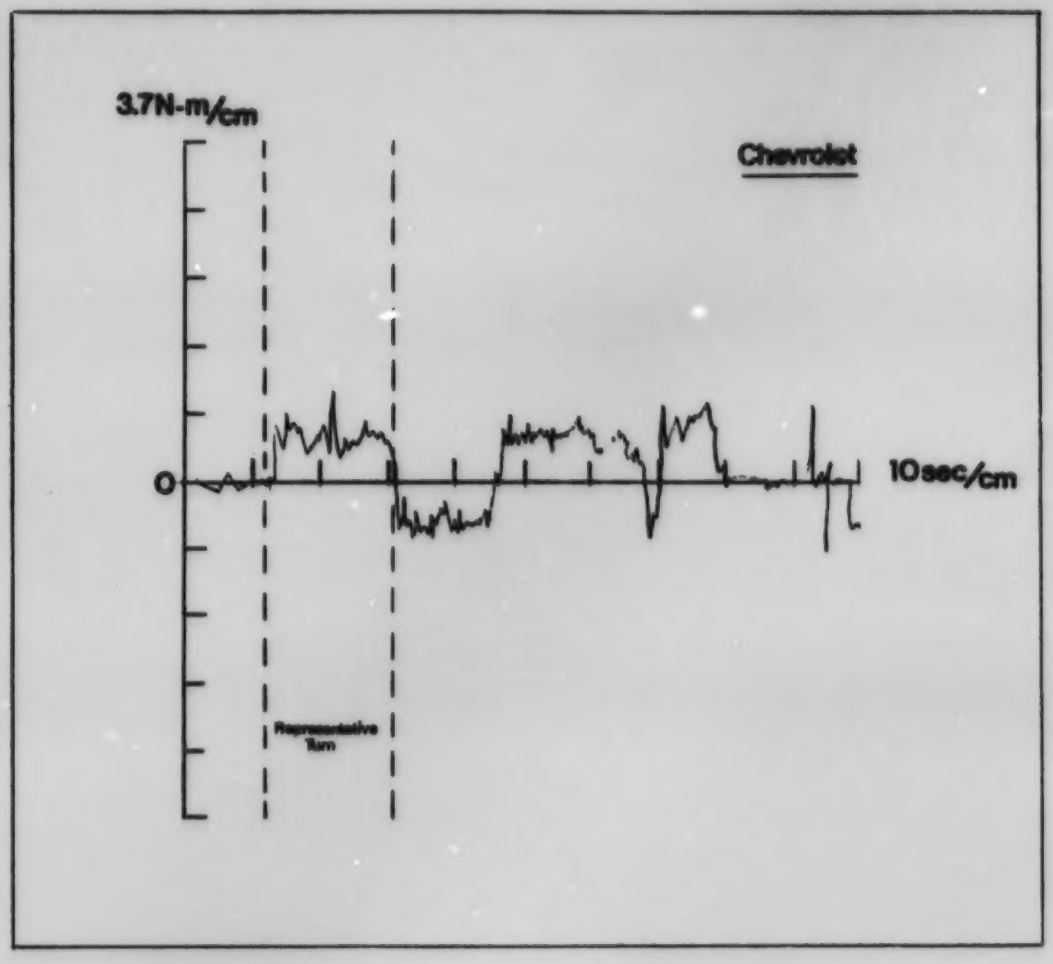

Figure 30 Steering wheel torque during low speed turning manoeuvres

8.4 Throttle-to-Brake Response Times

The time required to move the hand from the throttle control to the brake control was measured, in order to assess the safety of the control design. It was hypothesized that the close proximity between the two controls could retard response time, and could thereby constitute a safety hazard in situations requiring sudden deceleration of the vehicle. To assess this problem, the response times measured with the Elswick hand controls were compared with the response times measured in a conventional foot-controlled vehicle (1983 Toyota Tercel).

Response times were recorded using ribbon switches (taped onto the appropriate controls) to record hand (or foot) contact with each control. Opening of the throttle switch (as the hand or foot left the throttle control) and closure of the brake switch (as the hand or foot contacted the brake control) caused voltage spikes to be transmitted to an oscilloscope, so that the interval between these events could be timed. The ribbon switches used in the measurements required a very small force for activation (approximately 2 N).

Two test responses were measured: (1) moving from 1/4 throttle to contact the brake, and (2) moving from full throttle to contact the brake. In addition, the measurements for the Elswick Envoy were recorded with the hand braced against the steering wheel and with the hand free of the steering wheel, since either position can be used in controlling the vehicle. Seven healthy, neurologically normal subjects were tested. These subjects represented a wide range of body sizes (5th to 99th percentile) and ages (27 to 49 years). There were five males and two females. Each subject was asked to repeat the test response 10 times for each test condition. The trials involving the two different hand positions were conducted in an alternating order, so as to negate fatigue and/or learning effects.

The mean response times are listed in Table 11. The data were analyzed using a three-way analysis of variance. The three factors were taken to be: (1) the type of control (foot control, hand control with palm on the steering wheel, and hand control with palm off the steering wheel), (2) the initial throttle position (1/4 and full), and (3) the individual. Zero interaction between the individual and either of the other two factors was assumed. The following results were obtained: (1) no significant difference between 1/4 throttle and full throttle responses ($p=0.21$), (2) the palm-off responses were significantly faster than the palm-on responses ($p=0.000$), (3) the palm-on hand control responses were significantly faster than the foot control responses ($p=0.000$).

SUBJECT	HAND CONTROLS				FOOT CONTROLS	
	PALM ON STEERING WHEEL		PALM OFF STEERING WHEEL			
	THROTTLE		THROTTLE		THROTTLE	
	FULL	1/4	FULL	1/4	FULL	1/4
1	140	172	148	167	217	188
2	118	141	115	135	194	183
3	98	113	118	111	168	151
4	217	186	139	124	153	143
5	105	112	99	101	161	156
6	140	135	90	100	138	116
7	193	158	158	155	193	188
OVERALL	144	145	123	127	175	161

Note: response times are recorded in milliseconds.

TABLE 11 - Mean Throttle-to-Brake Response Times

These results indicate that the hand control design on the Elswick Envoy does not create a safety hazard by retarding the braking response in neurologically normal users. However, it is quite possible that users with certain neuro-motor disabilities would experience difficulty in making fast braking responses using these controls. Unfortunately, experimental study of this hypothesis was beyond the scope of the present study. As a general principle, it would seem advisable to use a single push-pull type of control to activate the throttle and the brake, thereby eliminating the time delay associated with the movement between two separate controls.

Chapter 9 INSTRUCTION MANUAL

9.1 Discussion

The instruction manual provided was inadequate in many respects. A critique of it in its present form would be lengthy and of little value.

The new vehicle owner manual would be well served by a manual which gives clear and continuous flow information. The contents of the present instruction booklet could be reorganized in the following format.

Introduction

Instumentation
- Instrument panel
- Ignition lock cylinder
- Warning indicators
- Speedometer
- Lights
- Windshield wipers
- Heat, ventilation

The complete instrument panel diagram should be one page, with all controls clearly labelled.

Before Driving Your Vehicle
- Wheelchair rear door entry and exit
- Wheelchair restraint
- Seatbelts
- Passenger seats
- Mirrors
- Steering
- Brakes

Starting and Operating Your Vehicle
- New vehicle break in
- Vehicle loading
- Starting
- Transmission
- Speed control
- Driving tips to save fuel

Getting to Know Your Vehicle
- Locks
- Windows
- Tires
- Radio

Vehicle Maintenance

Specifications and Capacities

Servicing Your Vehicle

Customer Assistance

Acessory Equipment

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REFERENCES

1. Aldman, Brattgard, Hansson. Safety during special transportation service trips - part one: Transportation in vehicles designed for handicapped. UMTA-CA 06-0098-78-2, 1974.

2. American Academy of Orthopaedic Surgeons. Joint motion, method of measuring and recording. Illinois: American Academy of Othopaedic Surgeons, 1965.

3. Canadian Transport Commission. Summary of Proceedings: Public Meeting on Problems of the Handicapped with Regard to Public Transportation Under Federal Jurisdiction. Ottawa: Canadian Transport Commission, 1980.

4. Daniels L, Worthingham C. Muscle testing, techniques of manual examination. 3rd ed. Philadelphia: WB Saunders Co., 1972.

5. National Aeronautics and Space Administration. Anthropometry for designers Vol.II: A handbook for anthropometric Data. Springfield: NASA Reference Publication 1024. Scientific and Technical Information Office, 1978.

6. O'Sullivan SD, Cullen KE, Schmitz TJ. Physical rehabilitation: evaluation and treatment procedures. Philadelphia: FA Davis Co. 1981.

7. Society of Automotive Engineers. 1983 SAE Handbook-Volume 2: Parts and components. Warrendale: Society of Automotive Engineers, 1983.

8. Society of Automotive Engineers. 1983 SAE Handbook-Volume 4: On-highway vehicles and off-highway machinery. Warrendale: Society of Automotive Engineers, 1983.

APPENDIX The EG ZO 3

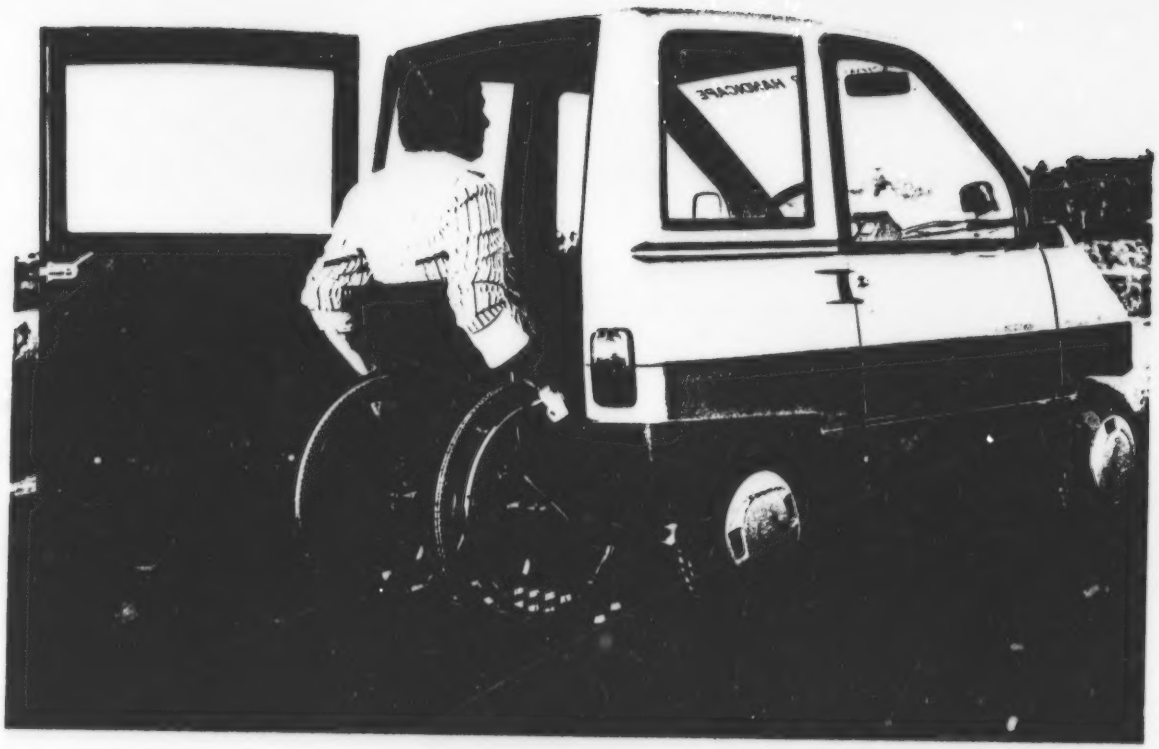

Figure 31 The EG ZO 3

Since commencing this evaluation one of the research team (Dr Fernie) had the opportunity of seeing the "EG ZO 3" H MINI CAR at an exhibition in the U.K.. This vehicle is produced by GATEAU INTERNATIONAL of France and appears to offer several advantages over the Elswick Envoy at a reduced cost. The vehicle is similar in appearance but has a lower top speed. It is available with gas, diesel, or electric power. Design features include powered opening and closing of the door, an elevating floor, and a restraint system that is adaptable for different wheelchairs. The door and floor are both operated by applying pressure to a special key ring that transmits the instruction to the vehicle. A single hand control operates the throttle and brake.